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NPD STATION DECOMMISSIONING: NUCLEAR PLANT AGING STUDIES USING NATURALLY AGED COMPONENTS AND MATERIALS

by

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ABSTRACT

After 25 years of operation, the NPD nuclear station is now being decommissioned. This offers an excellent opportunity to obtain samples of naturally aged plant components and materials for OH's programs related to nuclear plant aging. Senior OH and AECL management gave approval for the retrieval and testing of Priority I components and materials only, and these included pressure tubes, samples of large bore PHT piping, concrete samples, cable samples, motors, and in-situ tests on generator and electrical circuits. The scope of Phase 2 work related these components and materials is provided and it is recommended that adequate funds be provided to proceed with this work.

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EXECUTIVE SUMMARY

NPD STATION DECOMMISSIONING: NUCLEAR PLANT AGING STUDIES USING NATURALLY AGED COMPONENTS AND MATERIALS

After 25 years of operation, the NPD nuclear station is now being decommissioned. This offers an excellent opportunity to obtain samples of naturally aged plant components and materials for OH's programs related to nuclear plant aging. Since plant components at NPD had been exposed to their operating environment longer than any other CANDU plant, the examination of these components could help in identifying presently unknown aging mechanisms and thereby improve the long-term reliability of OH's currently operating nuclear plants. In spite of some differences in design, materials, and operating conditions, it is believed that the information obtained from the examination of NPD components and material would be directly useful to OH's nuclear program. A selection methodology was developed to select out of hundreds of plant components and materials those that would be of most value to OH's nuclear program. The selected components were prioritized into priority I, II and III components. Senior OH and AECL management gave approval for the retrieval and testing of priority I components and materials only and these included pressure tubes, samples of large bore PHT piping, concrete samples, cable samples, motors, and in-situ tests on generator, motors, and electrical circuits. The Phase I work related to retrieval of components and materials, and conduct of in-situ tests is now complete. The Phase 2 work is related to actual laboratory investigations of these naturally aged components and material samples. The scope of this phase of work is presently being defined by project leaders with input from design, operations, and research staff. Preliminary scope of work is included in Section 6 of this report. A COG proposal has been submitted for the actual implementation of Phase 2 work. It is recommended that this proposal be approved to provide adequate funds for Phase 2 work. It is recommended that the feasibility of starting a similar program of acquiring naturally aged material and component samples at Douglas Point NGS should be investigated.

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NPD STATION DECOMMISSIONING: NUCLEAR PLANT AGING STUDIES USING NATURALLY AGED COMPONENTS AND MATERIALS

1.0 INTRODUCTION

1.1 NPD Decommissioning

After 25 years of operation, NPD nuclear station has reached its final operational phase. It is anticipated that this final phase will consist of: defuelling, heavy water removal, decommissioning of all systems, and leveling all surface structures (except those housing the nuclear systems). During its 25 years of operation, there were no safety related accidents, and all safety-related systems functioned as required. The station was successfully used for demonstration of CANDU concepts and for staff training and development. According to a recently drafted program plan, the station should reach an unmanned state by the summer of 1988. This report discusses the potential utilization of NPD components and materials in support of OH's nuclear plant aging and life assurance programs.

1.2 Nuclear Plant Aging: Potential Impact on Safety, Reliability, and Plant Life

At present, Ontario Hydro's operating nuclear power plants are relatively young (oldest commercial power plant is about 16 years old) compared to the original design life of 30 years and the nominal financial service life of 40 years. However, by the year 2000, many nuclear units will be approaching close to the original design life of 30 years. Thus, the question of maintaining adequate safety and reliability of rather "old" plants and questions of life assurance and life extension will be of growing importance. Age-related degradation of plant components is complex and is not fully understood. However, because of the potential safety and reliability impact, work has already begun in this area in many countries.

1.3 Current Aging-Related Programs in OH

Within OH, the major activities in the area of nuclear plant aging are as follows:

1. Nuclear Plant Life Assurance (NPLA) Program
2. Equipment Qualification Program
3. Post-Service Examination
4. Condition Assessment Refurbishment and Upgrading (PICKUP) Program

1.3.1 Nuclear Plant Life Assurance (NPLA) Program: Is a proactive and a systematic program for controlling and managing age-related degradation of big ticket plant components. The main objectives of the program is to maintain the long-term reliability, and safety of nuclear plants during the nominal service life of 40 years. Full details appear in reference 1.

1.3.2 Equipment Qualification Program: The role of equipment qualification (EQ) in managing aging and maintaining operational readiness of essential safety-related equipment is well known. Within OH, the current studies in this area relate to the comprehensive EQ program at the new plant, Darlington NGS, and the EQ status review at the older Pickering and Bruce plants.

1.3.3 Post-Service Examination: An important part of the research and development programs related to understanding and managing aging of nuclear plant components is the examination of naturally aged plant components. However, access to naturally aged components of the desired type and vintage is generally limited. Potential sources of naturally aged components include failed and removed equipment from operating plants, and equipment from decommissioned plants.

1.3.4 Condition Assessment, Refurbishment, and Upgrading (PICKUP) Program

During the recent retubing outages (1984-87) of the Pickering nuclear station Units 1 and 2, a major inspection program was carried out to determine the condition of many of the plant critical components and upgrade deteriorated components. Similar programs are expected to be undertaken during the Pickering Units 3 and 4 retubing programs scheduled for 1989 and 1991 respectively.

2.0 USE OF NPD STATION FOR AGING STUDIES

Most of the R&D studies related to understanding of age-related degradation use artificially aged components under simulated service conditions. These studies, however, must be supplemented by examination of naturally aged components. Perhaps the most important rationale for the acquisition and testing of naturally aged components relates to the possible identification of presently unrecognized (unknown) synergistic aging mechanisms that could significantly impact component, structures, or system performance. Only naturally aged components could reflect the full range of possible detrimental effects resulting from internal processes and plant factors. Thus the laboratory investigations of naturally aged components could provide important general perspective on aging characteristics of nuclear plant equipment.

2.1 SOATIC Subcommittee Assignment Related to NPD Aging Studies

Subsequent to the decision to decommission NPD, a SOATIC (Senior Ontario Hydro and AECL Technical Integration Committee) Subcommittee comprising of Messrs. L.W. Woodhead, H. Irvine, D. Mills, and R. Green was set up to assess the significance of NPD to the long-term reliability of CANDU nuclear power stations. The Subcommittee felt that since plant components at NPD had been exposed to their operating environment longer than any other CANDU system, their examination could provide valuable information pertinent to aging degradation and long-term behaviour of similar systems in other CANDU stations. This Subcommittee then set up an intercompany Ad-hoc Task Group of OH, AECL-CO, and AECL-RC to make specific recommendations for the removal of NPD components and materials and for the conduct of in-situ tests at NPD prior to reaching its unmanned state. Since the

final NPD operation plan did not take into consideration any additional activities related to retrieval of components and materials, this Task Group had to work under tight schedules so as to be able to integrate these with the overall situ decommissioning plans and to modify NPD operational plan, if required.

On October 8, 1987, a presentation to the SOATIC Subcommittee was made by the Task Group. The Subcommittee approved all priority I items (see section 4.0 for details). They approved the extension of the final operation schedule caused by the component retrieval activities. They also approved the additional costs associated with these activities. Approval of the subsequent activities (Phase 2) requiring actual examination and studies in the R&D laboratories could be done on a more protracted schedule and the Subcommittee felt that the approval of funds and resources for this phase of work, should be left to the appropriate line managements or to the appropriate COG working parties.

2.2 Sources of Naturally Aged Components and Materials

Only naturally aged components reflect the full range of possible detrimental effects resulting from internal processes and plant factors such as external stressors, service wear, testing procedures, and maintenance practices. Evaluation of naturally aged components and materials is the only way, other than through plant incidents, to identify unexpected or synergistic aging and degradation mechanisms.

Despite their value, access to naturally aged components of the desired type and vintage is generally limited. Potential sources of naturally aged components are as follows:

1. Failed Equipment From Operating Plants

   The components are directly relevant to current plants and designs, but equipment of the specific type and with the age and service history desired for aging studies may not be "available". Also the side effects of the failure may compromise aging evaluation. In addition, this approach is not proactive in the sense that failure is not detected or prevented before it happens.

2. Removed Equipment From Operating Plants

   Operational equipment could be removed from operating plants under a replacement arrangements, but this could be very costly and may be feasible for a limited number of components only, e.g. pressure tubes. Similarly, selected in-situ aging evaluations could be conducted at operating plants, but these would be limited to the use of nondestructive techniques./2/ They may also interfere with the normal plant operation and outage schedules.

3. Equipment From Decommissioned Plants

   The best source of naturally aged components for aging studies is operational equipment from retired plants. A variety of components is available, including different vintages for replacement equipment. Equipment and material samples can be removed for detailed evaluations in offsite R&D laboratories. Also in-situ tests can be performed without concern for equipment or station operating schedules.

A review of the above options of the sources of naturally aged equipment shows that decommissioning of NPD offers an excellent opportunity to conduct in-situ assessments at an aged reactor and to obtain a variety of naturally aged and degraded components and material samples for detailed aging evaluations.

2.3 NPD Component and Materials Relevancy Considerations

Age-related degradation is complex because of a wide variety of materials, operating conditions, and degradation mechanisms. For the aging evaluations related to NPD components and materials to be useful, we have to consider their relevance to currently operating CANDU stations in terms of designs, materials, specifications, and operating conditions./2/

Figures 1, 2 and 3 show NPD station PHT system, moderate system, and secondary system conditions.

Table I provides a comparison of the operating parameters of PNGS-A and NPD nuclear power stations. As can be seen, there are some differences in flow rates and water chemistry, but in general the differences in operating parameters are not significant. It is felt that, the information obtained from NPD components and material samples would be useful to currently operating plants for the following reasons:

1. Since basic CANDU design of NPD is similar, the operational knowledge and experience obtained over the years is directly applicable to current CANDU power station operations.

2. Information obtained from aging evaluation of NPD components and materials would supplement aging information from failed or removed equipment from currently operating plants.

3. The in-situ measurements on NPD components, and the laboratory investigations of naturally aged components provide important general perspective and trends on aging characteristics of nuclear plant equipment.

4. NPD station equipment can be used to validate the results of a number of generic studies such as development of diagnostic and condition monitoring techniques.

5. It is impossible, by definition, to meaningfully evaluate naturally aged components if only new or current vintage equipment is considered to be relevant.(1)

It should be emphasized that the members of the Task Group in their selection and priorization of components and materials to be removed from NPD reviewed their relevance to current CANDU stations.

TABLE I
Comparison of Operating Parameters

PARAMETER	NPD	PNGS-A
Power Output	25 MWe	542 MWe
Efficiency	27%	30%
Operating Pressure (PHT)	7.2 MPa	8.7 MPa (outlet)
Coolant Temperature . inlet . outlet	 251°C 278°C	 249°C 293°C
pH	9.8 - 10.2	9.5 - 10.5
Pressure Tube Material	Zr-2 (2 tubes of Zr 2½% N_B)	Zr-2 (P1 & P2) and Zr 1½% N_B (P3 & P4)
Steam Condition . Pressure . Temperature	 2.75 MPa 220°C	 4.06 MPa 250°C

3.0 OBJECTIVES OF AGING PROGRAM AT NPD

The objective of the proposed programs (Phase 1 and Phase 2 - see Section 3.0) related to NPD components and materials is as follows:

1. To provide important general perspective on the aging characteristics of nuclear plant equipment and to improve our understanding of the long-term reliability and maintainability of operating CANDU power stations through investigations of potential degradation and failure modes.

2. To identify presently unrecognized (unknown) synergistic aging mechanisms that could have a significant impact on the long-term safety and reliability of operating nuclear power plants.

3. To help in resolving several generic issues of concern to OH, AECL, and AECB such as the validation of accelerated aging and remaining life prediction models, and the development of condition monitoring techniques.

4. To conduct chemical and geochemical investigations on naturally aged NPD samples to determine characteristics of tritium, C-14, and gamma emitting radionuclides; and to help resolve other radioactive waste issues.

4.0 NPD AGING EVALUATION TASK

The scope of NPD aging evaluations can be divided into the following two phases:

1. Phase 1 - retrieval of components and materials, and conduct of in-situ tests.

2. Phase 2 - offsite laboratory testing of naturally aged components and materials.

4.1 Phase 1: Retrieval of Components and Materials, and Conduct of In-Situ Tests

The Phase 1 work consists of the following activities:

1. Acquisition of selected naturally aged components and material samples.

2. Performance of in-situ tests and measurements on selected components and equipment at NPD.

3. Collection of historical data and records related to selected components. This includes design documentation, operational history, and maintenance record.

4. Packaging, decontamination, and storage of selected components and material samples.

5. Planning and coordination of above activities with NPD station staff.

4.2 Phase 2: Offsite Laboratory Testing of Naturally Aged Components and Materials

This Phase of work consists of the actual examination and studies of naturally aged components and material samples obtained during Phase 1. These studies are necessary to accomplish the overall objectives of the NPD program as outlined in Section 2.0 of this report. In particular, these studies would help in our understanding of the long-term reliability of CANDU stations through investigations of potential degradation and failure modes and the possible identification of presently unrecognized aging mechanisms.

5.0 NPD COMPONENT AND MATERIALS SELECTION PROCESS

One of the initial challenges of the NPD program was to select, out of the hundreds of possibilities, those components and material samples that would be of most value of OH's nuclear program. A selection methodology was developed and is described in the next section.

5.1 Selection Methodology

The key elements of the criterion for selection of NPD components and material samples are as follows:

1. Relevancy considerations and long-term benefits to OH's nuclear program.
2. Cost.
3. Man-rem expenditure.
4. Availability of naturally aged components and material samples from other sources.

The final selection of specific components and material samples to be acquired was accomplished with input from D&D Gen, TTSD, OHRD, stations, and AECL staff. To help in the selection process, a number of visits were also made to the NPD station.

The selected components were also prioritized into priority I, II and III components.

Priority I Components: are those components which would provide significant information and should be obtained even if it requires significant interference with NPD operation and results in an extension of final operation.

Priority II Components: are desirable components that should be obtained as long as it can be done within the NPD operational schedule. Priority II items should precede those of priority III.

5.2 Priority I Components

The listing of Priority I components is included in Table II. The organization identified as the proponent for each component is also identified in this Table. On October 8, 1987, the SOATIC Subcommittee approved work on all Priority I components.

TABLE II
Priority Items

ITEM	PRIORITY	ORGANIZATION RESPONSIBLE
1. Removal and Examination of Pressure Tubes	I	AECL
2. Samples of Large Bore PHT Piping	I	OHRD
3. Concrete Samples	I	OHRD
4. Cable Samples	I	OHRD
5. In-Situ Tests on Cables	I	OHRD
6. In-Situ Diagnostic Tests on Generators	I	OHRD
7. Motors	I	OHRD

OHRD - OH Research Division AECL RC - AECL Research Co.

5.3 Priority II and III Components

The Priority II and III components are listed in Table III. Excluded from this list are activities pertinent to decontamination, detailed radiological examination of NPD, and the final decommissioning related studies.

TABLE III
Priority II and III Items

ITEM	PRIORITY	ORGANIZATION RESPONSIBLE
1. Removal of SG tubes	2	OHRD
2. Visual Inspection of Civil Structures	2	OHRD
3. Repair of Concrete (Tests)	2	OHRD
4. In-Situ Tests on Motors	2	OHRD
5. Samples of Aged Dectronic Components	2	OHRD
6. Corrosion-Erosion Studies Related to Secondary Piping	2	OHRD
7. Detailed Radiological Examination of NPD, including C-14 and Tritium	2	OHRD
8. Examination of Valves	3	OHRD
9. Samples of PHT Pump Impeller	3	OHRD
10. In-Situ Examination of Pumps	3	OHRD
11. Retrieval of Aluminum Calandria Tubes	3	AECL
12. In-Situ Fuel Channel Rupture Tests	3	AECL
13. Examination of Fuel Channels	3	AECL
14. Examination of Batteries	3	OHRD
15. Examination of Pressurizer Components	3	OHRD
16. Examination of Reactor Internals	3	OHRD/AECL
17. Examination of Fuel	3	AECL/OH
18. Decontamination Related Studies	3	OH/AECL

6.0 STATUS REPORT ON PHASE 1 AND 2 ACTIVITIES

6.1 Pressure Tubes

Three pressure tubes have been removed from the NPD station. Results of the examination of these tubes will be presented by AECL in the near future. Thus this topic will not be discussed any further in this report.

6.2 Concrete

Background Information

Part of the decommissioning activities at NPD NGS comprises of testing of concrete cores. Civil Research Department was responsible for obtaining the cores from the various locations at NPD.

Objectives

The objectives of the R&D related to concrete are threefold:

(a) To help in understanding age related and service related degradation of normal and high density concrete in nuclear service.

(b) To determine the radionuclide content and activity, distribution of activity in the various types of concrete exposed to neutron and gamma radiation as well as tritium and C-14.

(c) Investigate the behaviour of certain radionuclides in cement, specifically, tritium and C-14.

The interest in studies (b) and (c) was spurred by the widespread use of cement based materials as structural materials for radioactive facilities (reactor structures and engineered barriers for radioactive waste disposal facilities) and as containers for irradiated fuel and other radioactive wastes.

Phase 1 Work

This phase of the work consisted of retrieval and packaging of the cores from 12 selected locations. This phase of the work is complete and the cores are stored in Radioactive Materials Laboratory.

Proposed Phase 2 Work

The work outlined below is being carried out by P.K. Mukherjee (Concrete Technology Section, Civil Research).

A detailed outline of the work program will be prepared. Following this, examination and testing of the concrete cores obtained during Phase I will be carried out. Physical tests together with the examination of microstructure of concrete will be conducted. A tentative list of testing and evaluation procedures is given below:

1. Visual examination - optical microscope
2. Density and absorption
3. Permeability
   - Air permeability
   - Water permeability
4. Compressive and flexural strength at ambient and elevated temperatures
5. Elastic modulus and stress - strain characteristics
6. Thermal properties
   - coefficient of thermal expansion
   - specific heat
   - thermal conductivity and diffusivity
7. Examination of microstructure
   - scanning electron microscope (SEM)
   - mercury porosimetry technique (MP)
8. Compositional changes of the cement paste - Thermogravimetry (TG)

The following proposed work is being carried out jointly by R. Dayal (Civil Research) and J. Krasznai (Chemical Research).

(a) Since some of the core sections will be examined destructively at the University of Toronto and at locations which are not licensed for radioactive materials handling, a set of criteria and procedures for assessing the radioactive hazards associated with handling the cores has been assembled. An assessment of the radioactive contamination of the cores which are to be sent to the University of Toronto is presently in progress to determine the packaging requirements for transportation and the radiation hazards associated with destructive examination of the cores.

(b) The core sections from location 2 which have been subjected to a significant flux of neutrons will be gamma scanned to determine the major gamma emitting isotopes contributing to the radioactivity.

(c) Chemical Research will take radial samples to a depth of 3 cm along the length of the sections from location 2 and 12 using a small masonry drill bit. The cement debris will be analyzed to determine the specific activities of tritium, C-14 and gamma emitting radionuclides.

(d) Analytic Services Section will be requested to develop a procedure to determine the specific activity of the long lived calcium isotope (Ca-41) which is expected to be present in the reactor vault end section of location 2.

(e) Information obtained in tasks (b), (c) and (d) will provide base line data for the geochemical investigations proposed by R. Dayal of Civil Research. For this part of the study, axial sub cores (4" diameter) will be taken from high activity areas of cores 2 and 12 and sectioned into 0.5 cm thick slices perpendicular to the cores axis.

(f) Each section will be analyzed for C-14 and gamma emitting radionuclides to establish their depth profile in a given core.

(g) Radionuclide data in each section will be correlated with concrete material and textural properties to obtain information on the distribution and partitioning of radionuclides, in particular, C-14 amongst the various concrete constituents.

(h) Location 12 is in the sump area of the dump tank which was expected to have been exposed to high concentrations of tritiated heat transport and moderator water over the operating lifetime of NPD. These core sections were coated with an epoxy paint to minimize the loss of absorbed tritium after core removal. It is planned to determine the tritium activity in these samples as a function of distance from the tritium source and the rate of tritium desorption from the cement in both dry and humid air. Since location 12 was likely submersed in heavy water at one time or another there may be other radionuclides present in the concrete not observed in the cores from location 2. The characterization of these radionuclides will also be carried out.

Benefits of the Program

In this project, naturally aged concrete exposed to real in-service conditions will be examined to characterize the physical and chemical properties of the concrete cores and attempt to relate the changes observed in these properties to service conditions. This is of significant importance since majority of existing research studies are based on data from simulated service conditions. In addition, the study will provide unique data on radionuclide distribution in normal and high density concretes which would be useful in the performance assessment of concretes being used for radioactive waste storage and disposal.

Estimated Cost of Phase 2 Work

The estimated cost is $160,000 to $200,000 per year depending on the need for special testing equipment. The duration of the proposed program is two years.

6.3 Cables

Background Information

In a radiation environment, the predominant failure mode of electrical control and power cables is the embrittlement of the insulation resulting in the rupturing or cracking of the insulation during temperature cycling or cable movement. Initial qualification of the cables for service in NPP environment involves pre-conditioning of cables by accelerated aging techniques before testing under postulated accident and post-accident conditions. A major concern is whether the accelerated aging sequences provide valid data for life expectancy prediction. In particular, there is a concern that the low radiation dose rates, in combination with operating temperatures, cause greater degradation than predicted by laboratory accelerated aging studies. Validation of the accelerated aging sequences can be made only by comparisons with naturally-aged cables. Cable samples obtained from NPD NGS, which has been permanently shut down after 25 years of service, provide a unique opportunity to extend the understanding of field aging of insulating materials.

Objectives

1. To determine the degree of insulation degradation and to relate damage to radiation dose and operating temperature.

2. To determine the validity of accelerated aging techniques for insulation materials by comparison with actual field degradation results.

3. To establish whether the insulations used are sensitive to dose rate effects.

4. To determine the functional capability of naturally-aged and further aged cable samples under DBE/post-DBE conditions.

Phase 1 Work

Identify and remove electrical control and power cables relevant to current CANDU NPPs. Collect service condition data (radiation dose rates and total dose received, operating and ambient temperatures, and duration of service).

Proposed Phase 2 Work

1. Select cables from the containment area that would be most relevant to existing nuclear stations. Determine condition of cables (electrical and physical) and irradiate cables to an accident dose followed by a LOCA and post-LOCA exposure. A full line to line voltage will be applied between different phases, where applicable. (The profile of LOCA and post-LOCA conditions for the tests will be decided in consultation with AECB and Design & Development Division of Ontario Hydro.) In addition, perform the same tests on the cables from NPD containment area further preconditioned by accelerated aging techniques.

2. Assess degradation of cable insulation and predict remaining life using physical and chemical means. Determine whether the damage caused by the low radiation fields experienced in the plant environment can be predicted by the high dose rates used

during qualification. This will be accomplished by exposing cable lengths, that have not been irradiated, to accelerated radiation and comparing the results to those obtained on materials from the containment area.

Benefits of the Program

The information obtained will provide data to validate the current accelerated procedures used to qualify cables for 40 year life. The techniques developed to evaluate polymer aging will be used to assess remaining life of polymers and whether a cable will withstand a DBE condition.

Estimated Cost of Phase 2 Work

The estimated cost of the program is $95,000 per year for three years. For 1988/89, $65,000 has been obtained from CNS.

6.4 In-Situ Testing of Cables

Background

Very little objective information is available on how effective existing diagnostic tests are in predicting cable insulation condition. The shutdown at NPD permitted the performance of these diagnostic tests, and comparison of the results with destructive testing and cable dissection. The latter are the only objective means, known at present, for assessing insulation condition.

Objectives

Assessment of the usefulness of conventional cable diagnostic tests for predicting the condition of the cable insulation systems.

Phases 1 and 2

In January and June 1988, a number of power, control, and instrumentation cable circuits became available for nondestructive evaluation and destructive testing at NPD. To date, a total of eight 2.3 kV, one control and five 600 V cables have been tested. All the power cables were unshielded and insulated with SBR, each circuit consisted of three conductors. The instrumentation cable was unshielded and insulated with PVC. Length of the cables ranged from 30 to 200 m.

The basic strategy adopted in the test program was to subject the cable to a wide range of diagnostic tests, break the cable down and then, where feasible, examine the faulted cable with the diagnostic tests. These tests included, insulation resistance, polarization index (PI), capacitance, dissipation factor, partial discharge, high voltage dc ramp, time domain reflectometry (TDR), and impedance as a function of frequency.

With the exception of the capacitance and dissipation factor test and partial discharge testing, the other techniques are only sensitive to fault conditions. High voltage dc ramp testing cannot be considered truly nondestructive since there is always a finite risk of the cable breaking down with this type of test. Insulation resistance and PI are sensitive to surface condition and the presence of moisture rather than more subtle degradation processes within the insulation. All of the above tests suffer from the fact that the cables tested are all unshielded thus lacking a well defined ground plane, a necessary prerequisite for the techniques employed to have a reasonable probability of success.

Benefits of the Program

To date, only a partial analysis of the results has been performed. Initial results indicate that the data form the diagnostic tests cannot be correlated with the measured breakdown voltages. The difficulties inherent in testing unshielded cables require further consideration. Cable samples were removed from NPD and shipped to the laboratory for dissection and analysis.

Estimated Cost of Phase 2 Work

Estimated cost is $5,000 (for electrical work).

6.5 PHT Piping

Background Information

Primary piping and welds in NPD primary heat transport system have been exposed to a high pressure and high temperature environment for its entire service life. The large and small diameter pipes are unique in that they provide a rare opportunity to investigate the age related degradation of carbon steel pipes and welds in a nuclear plant after twenty years of service.

Objectives

Determine fatigue (S-N curves and fatigue crack growth curves) and fracture toughness properties of carbon steel pipes and welds from NPD-NGS at the end of service life. Determine conventional mechanical properties such as Charpy, tensile and hardness welds. Compare these properties against ASME Code data and as received material properties, if available. Determine the degree of material property degradation.

Phase 1 Work

In accordance to the discussions with AECL, D&D, CNS and OHRD the following heat transport and steam drum samples were removed from the boiler room.

1. A 2' x 3' section of steam drum shell (7/8" thick SA212B).
2. A 2' section of 6" diameter HTS pipe (SA106B, SCH 80 with a long radius elbow attached).
3. A 4' section of 4" diameter HTS pipe (SA106B, SCH 80 with a 45° elbow attached).
4. An 18" diameter section of HTS surge tank shell with a 6" diameter nozzle attached.
5. A 3' section of 1.5" feeder pipe (SCH 80 carbon steel from PH-L103).
6. Two 1.5" elbows from feeder pipe (SCH 80 carbon steel from PH-L103).
7. Two 2' sections of 12" diameter HTS primary pump suction pipes (SA106B, SCH 80 carbon steel, both with long radius elbows attached).

The total dose for this work was approximately 200 mrem. The samples will be decontaminated at CRNL before shipping to Hydro Research. Phil Simpson of CRNL will arrange for small sections of samples to be removed before decontamination for surface examination by the Chemistry and Corrosion branch of CRNL.

Proposed Phase 2 Work

A general direction of work has been established from discussions with the interested groups. The SA212 steam drum material will be used to determine fatigue and fracture properties of this class of steel. The SA212 is a discontinued grade of material. However, it has been used extensively for pressure vessels in Pickering Units 1 to 4. Therefore this data may be useful to support life assurance issues for these Units. The 12" diameter A106B pipes will be used to determine fatigue and fracture properties of large diameter PHT pipes and welds. Post weld heat treatment was not required for 4" and 6" diameter pipes. Therefore, these samples can be used to investigate possible strain aging effects. The surge tank nozzle weld will be examined non destructively for signs of thermal fatigue damage and the feeder pipes will be used for finding end of service mechanical properties. The specific work program is not fully defined yet. Input is required from D&D Generation, Operations, OHRD and AECL to complete this process.

Benefits of the Program

As indicated earlier, the SA212B steel has been used for pressure vessels in Pickering Units 1 to 4. The SA106B piping steel has been used in the PHT systems of all Ontario Hydro nuclear plants. Therefore, data obtained from NPD samples can be used to support life assurance issues. This work may also be useful to develop material aging models for similar materials used in nuclear plants. The benefits gained from this work will be tempered by the lack of base line data. It has not been possible to locate any information on as received material properties and on weld specifications. A good description of service transients is also missing.

Estimated Cost of Phase 2 Work

The project is expected to continue over two years at a cost of $80,000 to $100,000 per year.

6.6 Motors

Background Information

In a nuclear generating station, the role of motors is more critical than that prevalent in conventional plants. However, just as for the case of generators there is, as yet, no proven objective means of assessing the condition of the insulation system which is critical to the operation of the motor. In order to gauge the effectiveness of conventional diagnostic techniques (e.g. capacitance, dissipation factor, partial discharge, insulation resistance, polarization index, etc.), it is necessary to perform a similar program of investigation to that for a generator. That is, examine insulation condition with the commonly used diagnostics and then attempt a correlation with breakdown voltage.

Objectives

By using various diagnostic techniques, assess the condition of the insulation system of motors which have been operating in a nuclear environment. A second phase of this program is aimed at investigating the performance of the insulation system under LOCA conditions.

Phase 1 Work

Three 2.3 kV motors have been procured from NPD and shipped to OHRD.

Proposed Phase 2 Work

An experimental program will be initiated to explore the correlation between diagnostic test results and breakdown voltage. In addition, the interturn breakdown voltage is obtained to provide data on the health of this component of the insulation system. It is considered highly probable that interturn failure is a direct precursor to main groundwall breakdown. Experiments will be performed at Ontario Hydro's Nuclear Pump Test Complex.

A second program related to the performance of motors under LOCA conditions will be undertaken. This program requires a suitable test chamber as well as extensive mechanical and electrical setup and instrumentation. Therefore the work is proposed in three stages:

1. Feasibility. A small motor, from Douglas Point or NPD, will be located and procured and a suitable test chamber identified. Apparently a chamber at Westinghouse in Hamilton was used in 1982 to test a Pickering PHT motor under LOCA conditions.

2. Static Test. Assuming that a suitable motor and test chamber are available, static tests under LOCA conditions will be performed. The motor winding, including termination box, will be subjected to the types of electrical diagnostic tests described above. Then the motor, including termination box and some length of cable, will be exposed to simulated LOCA conditions (temperature, pressure, humidity and radiation) with line to ground rated voltage applied to the winding. If the motor does not fail, it will be dried and the same diagnostic tests done. No further testing will be required if either (a) the motor fails during simulated LOCA, or (b) the characteristics of the motor, as determined by diagnostic tests before and after exposure to LOCA conditions remain substantially the same. If neither of these conditions is met, then stage 3 will be required.

3. Dynamic Test. The motor will drive full load under LOCA conditions. This will require proper mechanical setup for the load and electrical installation. Diagnostic tests will be conducted before and after LOCA simulation. The motor will be kept under post-LOCA conditions and its operation in this state will be compared with the pre-LOCA case. In addition to the electrical tests, including repeated starts and stops, lubricants and bearings will be examined. The profile of LOCA and post-LOCA conditions will be decided in consultation with AECB and Design & Development.

Estimated Cost of Phase 2 Work

Estimated cost is $105,000 (assuming availability of a test chamber).

6.7 In-Situ Tests on Generators

Background

To ensure the reliable operation of generators, it is necessary to have confidence in the integrity of the stator, rotor and core insulation systems. A number of nondestructive diagnostic tests exist which are designed to provide an indication of the health of the insulation system,

particularly in stator windings. However, to date, there has been no systematic study of how effective these diagnostic tests are in providing an estimate of the remaining life of a rotating machine. Some Japanese work which focuses on the formulation of predictive equations derived from diagnostic test data has been published. However, these equations have only been applied to laboratory scale models and not full size generators.

Objectives

Perform, in a systematic manner, diagnostic and destructive tests to determine: a) the usefulness of present conventional diagnostic tests, and b) the validity of predictive equations.

Phase 1 Work

With the availability at NPD of a 13.8 kV, 20 MW turbine generator, it was possible to assess the usefulness of some common diagnostic tests in relation to assessing the general condition and remaining life of the machine. In this case, an objective indicator of end of life can be measured by applying an increasing ac voltage to individual coils, until they break down.

Diagnostic tests performed included:

- partial discharge measurements
- capacitance and dissipation factor
- insulation resistance and polarization Index (PI)

These tests were performed on phases, parallels and individual coils. On completion of the diagnostic phase, the individual coils were broken down by ac, dc or impulse voltage.

Proposed Phase 2 Work

Coils, removed from the generator at NPD, are now undergoing laboratory voltage endurance testing. Samples of failed coils were returned to the laboratory for dissection and analysis.

Benefits of the Program

Preliminary results of this testing show that there appears to be little or no correlation between breakdown voltage and the results of diagnostic testing.

Estimated Cost of Phase 2 Work

Estimated cost $10,000.

7.0 BENEFITS AND COST

7.1 Benefits

Benefits of the proposed Phase 2 programs for specific component and material samples have already been described in Sections 6.2 to 6.7 of this report. Generic benefits are outlined below:

1. Due to the effects of aging, nuclear plant equipment safety and reliability may decline. Only naturally aged components could reflect the full range of possible detrimental effects resulting from internal processes and plant factors. Examination of naturally

aged NPD components could help to identify unknown aging degradation mechanisms relevant to OH's currently operating nuclear stations. This could help in preventing costly forced outages and also in prolonging plant equipment life through timely changes in operating and maintenance practices.

2. The NPD aging program outlined in this report could help in developing generic capabilities in the areas of surveillance, diagnostic and condition monitoring techniques, remaining life prediction models, and validation of accelerated aging techniques.

3. The NPD aging program would benefit OH's other programs in the area of nuclear plant aging, namely NPLA, EQ, Condition Assessment, and Refurbishment Programs.

7.2 Estimated Cost

Full details of costs for Phase 2 work on naturally aged samples of concrete, cables, PHT piping, motors, and generators, are included in Sections 6.2 to 6.7 of this report. Total funds required on a per year basis for a duration of 3 years are summarized below:

Concrete	$130,000
Cables	95,000
PHT Piping	60,000
Motors	40,000
Generator	10,000
Total	$335,000 per year for 3 years

8.0 CONCLUSIONS

1. It is generally agreed that aging degradation of plant components cannot be stopped but can be slowed through proactive and systematic programs of controlling and managing aging. The examination of naturally aged components from the NPD station could contribute significantly towards OH's programs in the area of understanding and managing aging.

2. In spite of some differences in design, materials, and operating conditions, the information obtained from the examination of NPD components and materials would be directly useful to assuring the long-term reliability and safety of OH's currently operating nuclear plants as outlined in Section 2.3.

3. The proposed Phase 2 program related to naturally aged NPD components and materials appears to be cost effective. It is expected to help in early detection of age-related degradation of components in our currently operating nuclear plants.

9.0 RECOMMENDATIONS

1. The Scoping studies related to concrete, cables, PHT piping, and motors should be completed to finalize the scope of Phase 2 work on NPD components and materials.

2. To supply funds for Phase 2 activities, the COG proposal (see Appendix A for details) submitted for 1989-90 fiscal year should be approved.

3. If additional samples of naturally aged components and materials are required, we should review the feasibility of acquiring these from the already decommissioned Douglas Point nuclear station. This could be further supplemented with samples obtained from failed components in operating plants.

4. OH's efforts related to examination of naturally aged components should be coordinated with similar efforts in other countries (e.g. the Shippingport station decommissioning program in the U.S.).

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ACKNOWLEDGMENT

The authors would like to acknowledge the cooperation and assistance of NPD station staff. We would like to acknowledge the assistance of Dr. S. Kupca (CRNL), Mr. D.M. Hayter (D&D Gen), and other staff in OH's operations and design departments.

REFERENCES

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2. "The Shippingport Atomic Power Station - A Source of Power Plant Aging Information" by R.P. Allen, A.B. Johnson, Jr., and J.P. Vora. Presented at June 29-July 3, 1987, IAEA International Symposium on Safety Aspects of the Aging and Maintenance of Nuclear Power Plants.

3. "NPD As a Source of Information to Improve the Long-Term Reliability of Existing CANDU Stations", Issued September 30, 1987, and prepared by a Task Team of S. Kupca, J. Chadha, D.M. Hayter, I. Daly, A.D. Boothroyd, P. Simpson, and C. Ells.

NPD SYSTEM CONDITIONS

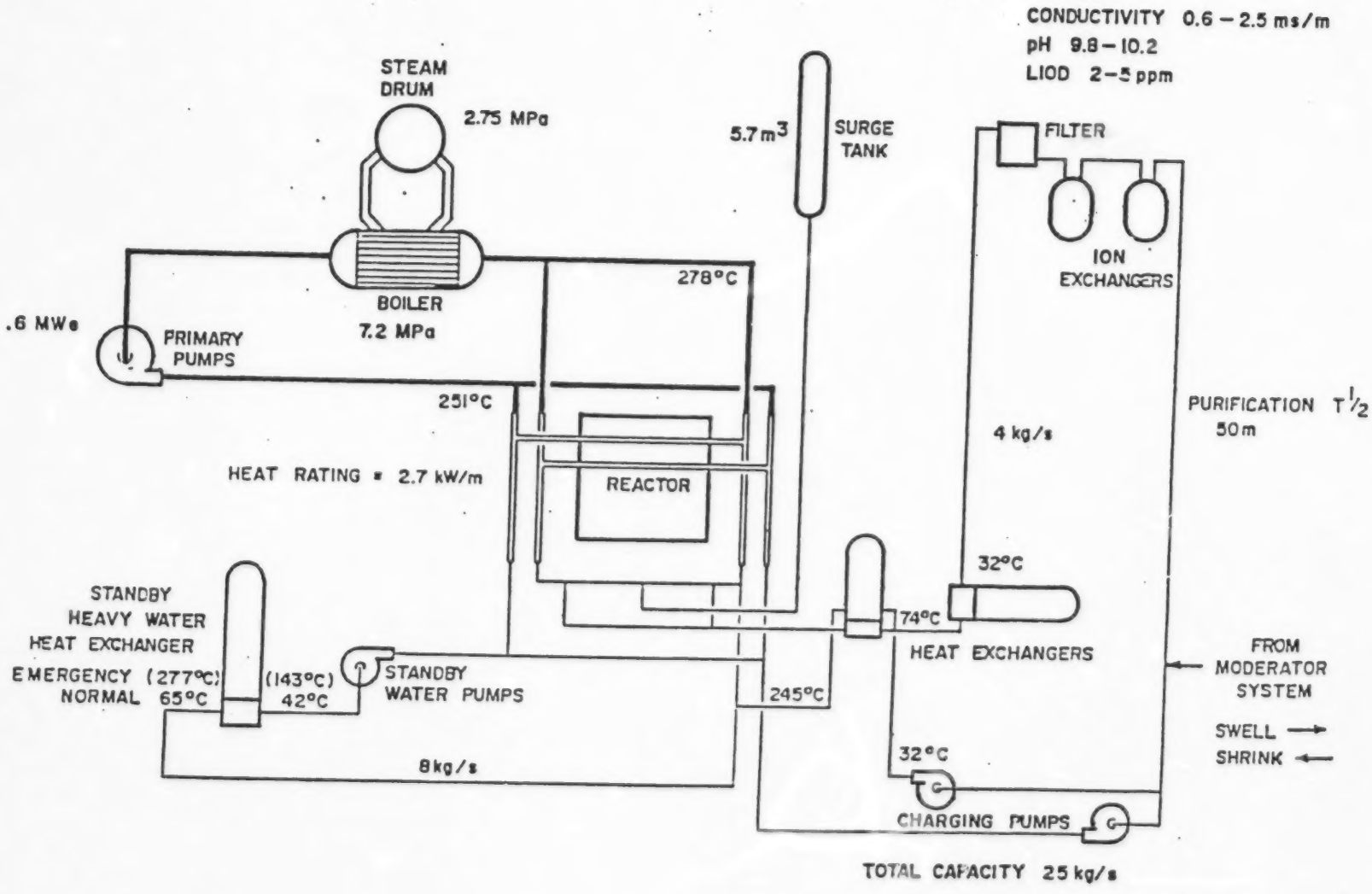

FIGURE 1 - NPD PRIMARY SYSTEM CONDITIONS

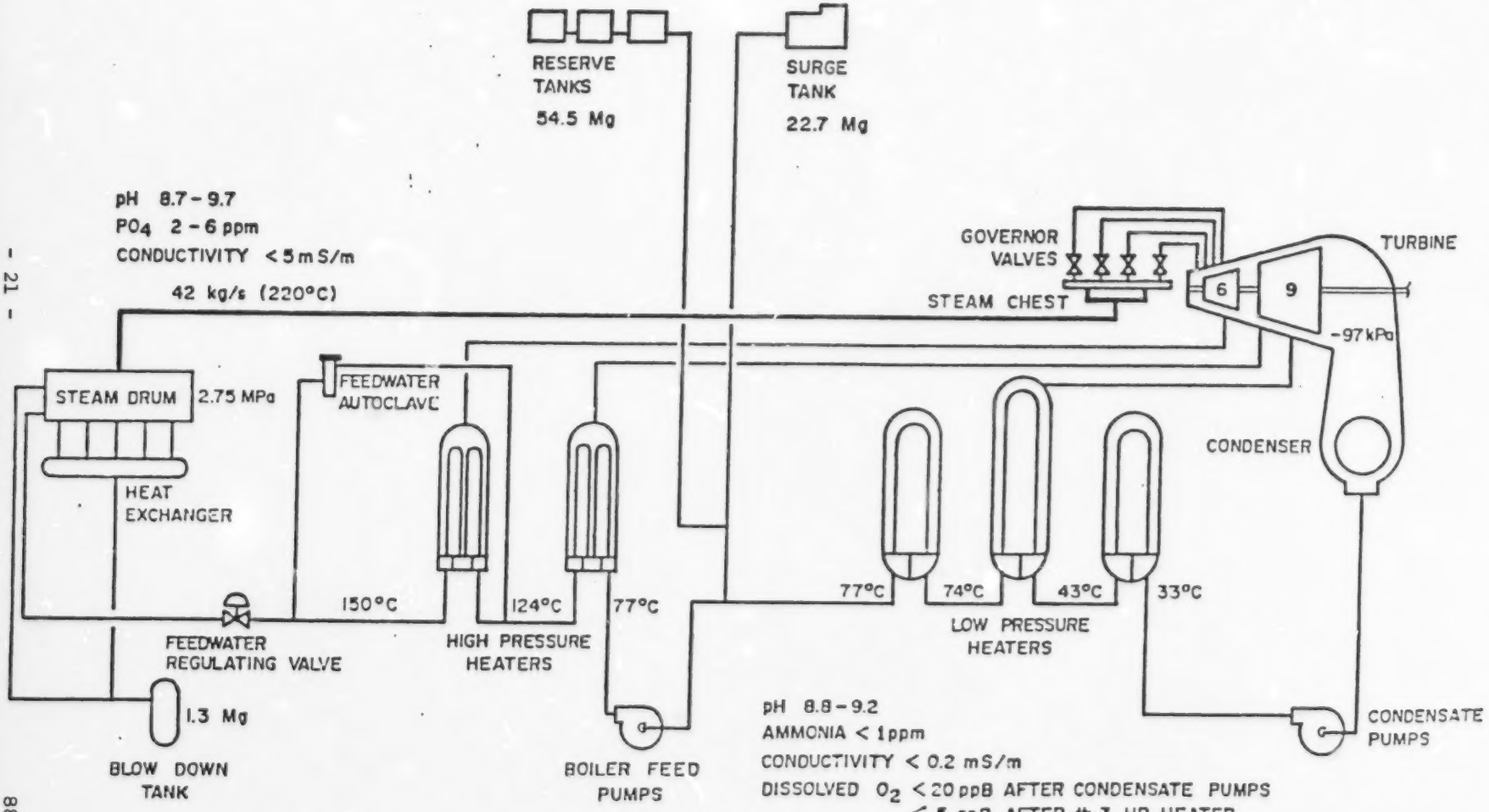

FIGURE 2 - NPD SECONDARY SYSTEM CONDITIONS

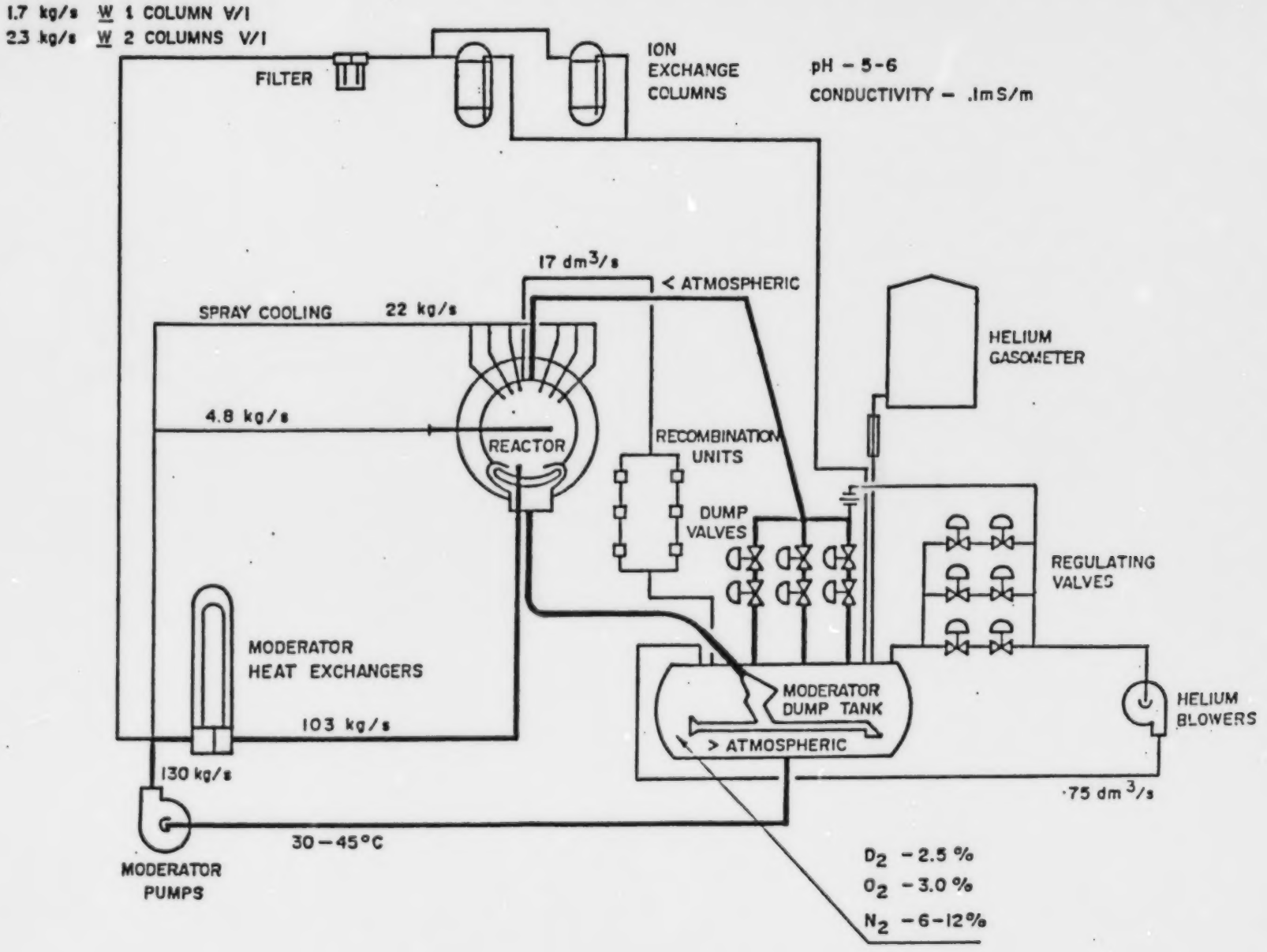

FIGURE 3 - NPD MODERATOR SYSTEM CONDITIONS

Research Division
800 Kipling Avenue, Toronto, Ontario, Canada M8Z 5S4

June 20, 1988

FILE: 825.113(T)

Mr. C.A. Kittmer
AECL-RC, Station 48
Chalk River Nuclear Laboratories
Chalk River, Ontario
K0J 1J0

Dear Mr. Kittmer:

COG Preliminary Proposals for 1989/90
COG Working Party #1 - Process Systems and Equipment

With reference to your letter of June 2, attached please find a copy of the preliminary proposal entitled "Investigations on Naturally Aged Material Samples Removed from NPD." As is clear from my covering memo to J. Webb, the proposal has already been considered by the CANDU Technology Technical Committee during their meeting of June 16. There appears to be good support for this work. I am sending this proposal to you for your information. In my opinion, this proposal would fit in well within the mandate of COG Working Party #1 - Process Systems and Equipment. I would appreciate it if you could include this proposal in your initial plan for the 1989-90 fiscal year.

If you have any questions, please do not hesitate to call me.

J.A. Chadha
Section Head
Applied Mechanics Section
Mechanical Research Department

Attachment

cc G.J. Clarke
R.T. Hartlen

Telephone (416) 231-4111 Telex No.: 06-984706 Facsimile (416) 231-9679

CANDU Owners Group

CANDEV Program

preliminary proposal

title: Investigations on Naturally Aged Material Samples Removed from NPD	w.p. number: CANDU Technology Tech. Comm
working party: CANDU Technology Technical Committee	proposed by: J. Chadha, OH Research

benefit: [X] safety [ ] licensing [X] reliability [X] cost reduction [ ] other

brief description of benefit

The objectives of this proposal are to acquire naturally aged selected plant components and material samples, obtain data and records, and conduct laboratory post service examinations (in-situ tests have already been completed) and tests of NPD station equipment and materials. The results of these investigations would be useful in understanding and managing aging, and in maintaining the long-term safety and reliability of CANDU nuclear power plants.

cost $K	previous years	current fiscal year	5 year estimate 19 /19	19 /19	19 /19	19 /19	19 /19
			300K	300K	250K	250K	250K

proposed place of work: [ ] CRNL [ ] WNRE [ ] AECL-CO [X] OH other:

type: [X] generic project:

brief description of proposed work (with major milestone schedule)

The NPD station, now undergoing decomissioning, is a major source of naturally aged equipment and material samples in support of understanding and managing aging degradation of nuclear plant components. OH's efforts related to NPD nuclear station components and material samples have been divided into two phases.

The Phase 1 work consists mainly of acquiring selected components and samples of materials, obtaining data and records, and performing in-situ assessments. This phase of work is progressing well and is nearing completion. In addition to in-situ tests, the following samples have been obtained:

1. concrete samples from various plant locations
2. cable samples from various plant locations
3. PHT piping samples including feeder pipes
4. motors
5. steam generator tubes
6. generator in-situ tests and assessment of insulation.

This proposal covers the next phase of work (i.e. Phase 2) which consists of laboratory investigations and testing of material samples obtained during Phase 1. The main objectives of these proposed investigations is as follows:

1. To improve understanding of the long-term safety, reliability and maintainability of operating power plants
2. To help in understanding age-related degradation and failure mechanisms
3. To validate remaining life prediction models
4. To develop and validate diagnostic and condition monitoring techniques
5. To develop a fitness for service criterion.

The first step in Phase 2 work will be to conduct scoping studies to finalize and prioritize the scope of investigations on these samples. Input from design, operations and research staff of utilities and AECL will be obtained.